

CURRENT PRACTICES IN EARTHQUAKE PREPAREDNESS AND MITIGATION FOR CRITICAL FACILITIES

JAMES E. BEAVERS

In this paper an attempt is made to briefly address the broad issues of earthquake preparedness and mitigation for critical facilities. Critical facilities considered herein are divided into two major groups: industrial and public.

Critical industrial facilities are defined as those facilities that, if damaged by an earthquake occurrence, could result in the release of substances harmful to the public, employees, or the environment or that could result in what owners consider as unacceptable financial losses. Examples of such facilities are nuclear power plants, chemical processing plants, research and development facilities, and high-technology manufacturing plants.

Critical public facilities are defined as those facilities that, if damaged by an earthquake occurrence, could result in large numbers of the public experiencing life, life-support systems, or financial losses. Examples of such facilities are hospitals, schools, stadiums, fire stations, dams, and bridges.

CURRENT PRACTICES

Practice vs Hazard

Current practice today is actually based on the perception of the earthquake hazard. All one has to do to recognize this is to compare earthquake design practice in the State of California to that in the State of Tennessee for example. In California, the perception is that there is an earthquake hazard, rightfully so. As a result, there are uniformly accepted seismic preparedness and mitigating practices, primarily in the form of accepted seismic design codes. In Tennessee, the perception is that there is no earthquake hazard, which is wrongfully so. As a result, not only are there no uniform seismic preparedness and mitigating practices, they are virtually nonexistent.

Dr. Beavers is Manager, Civil and Architectural Engineering, at Martin Marietta Energy Systems, Inc., Oak Ridge, Tennessee. He presented this paper at the FEMA Earthquake Education Curriculum Workshop held at the National Emergency Training Center, Emmitsburg, Maryland, June 27-29, 1984.

Four Levels of Practice

Regardless of the general perception of the earthquake hazard, today's practice in earthquake preparedness and mitigation for critical facilities from an engineering point of view can be divided into four general levels:

Level I--Complex earthquake hazard evaluation and facility seismic analysis and design as is conducted for nuclear power plants (U.S. Nuclear Regulatory Commission, 1975).

Level II--Earthquake hazard evaluation and seismic analysis and design as is conducted for an important chemical plant or, on occasion, possibly a hospital (Manrod et al., 1981).

Level III--Normal earthquake hazard evaluation and facilities analysis and design procedures as is conducted using the Uniform Building Code (UBC) or similar codes (International Conference of Building Officials, 1982; Structural Engineers Association of California, 1975).

Level IV--No earthquake hazard evaluation or facility seismic analysis or design provisions except for the inherent lateral resistance provided by wind analysis and design requirements.

Level I provides for a thorough evaluation of the earthquake hazard at the location of interest to the point of simulating the expected ground motions. The ground motions are then used as input to a rigorous seismic analysis of the facilities followed by detail design and documentation procedures. In many cases, Level I is considered as a very conservative approach to earthquake preparedness and mitigation.

Level II generally represents an adjusted medium between the approach in Level I and the approach used in Level III. The Applied Technology Council provisions (Applied Technology Council, 1978) represent a Level II approach for buildings. Manrod and co-workers (1981) discuss a Level II approach for preparedness and mitigation of existing critical industrial facilities.

Unfortunately, the preparedness and mitigation actions taken for most structures built in the United States today, many of which may be considered critical, fall under Level IV.

Except in California and one or two other states, there are virtually no adopted earthquake hazard evaluation or seismic analysis and design guidelines or codes in the cities, counties, or municipalities.

Levels of Application vs Critical Facilities

All nuclear power plants being constructed today fall under the strict seismic evaluation, analysis, and design requirements set forth by the U.S. Nuclear Regulatory Commission identified herein as Level I. Other

similar critical facilities, such as plutonium facilities, generally fall under the same requirements.

Chemical processing facilities, uranium enrichment facilities, and high technology manufacturing plants usually will fall into the Level III approach and, in some circumstances, Level II at the discretion of the owners--be they government or private industry. However, in many cases, using the minimum requirements of the UBC seismic design provision (the Level III application) may not be adequate for such facilities.

Critical public facilities such as dams and bridges may also fall under Level II and III seismic provisions depending upon the perceived earthquake hazard of the builder/owner. Schools, hospitals, fire stations, and stadiums will fall under the seismic provisions as described in either Level III or IV. Since the mid-1970s, most hospital designs fall under the Level III procedures. However, hospitals built before the mid-1970s and schools (except California), fire stations, and stadiums built today may actually fall under Level IV.

All critical facilities, as a minimum, should meet earthquake preparedness and mitigation requirements as defined in the UBC and, in many cases, go beyond the requirements of the UBC. However, as a cautionary note, it must be remembered when using the UBC, especially for industrial facilities, that it is a building code and judgment must be used where the code does not directly apply.

Today's Application

Although it was stated above that most structures built in the United States today are not designed to earthquake preparedness and mitigation provisions (a Level IV approach), nor are such provisions required by law, a process is occurring in this country where such provision are being applied more and more each day. This process is happening because of the educational program occurring within the professional groups (engineers, architects, scientists, etc.) and the liability responsibilities of such professionals. For example, most engineers are now aware of the need for earthquake hazard preparedness and mitigation practices in the design of any new facility. Although no local enforcement codes may require such procedures, architects and engineers are acutely aware of recent decisions in the courts where following the minimum requirements of building codes is not justification for not using prudent engineering judgment. As a result, many architects and engineers are now applying earthquake hazard preparedness and mitigation provisions in their facility design. For critical facilities, architects and engineers usually have no trouble convincing the builder/owner of the necessity for such provisions and the builder/owner is willing to accept the additional costs. However, for noncritical facilities, it is extremely difficult for the engineer or architect to convince the builder/owner of the long-term cost benefit of applying such provisions, and in many cases, the builder/owner will refuse--creating a professional dilemma for the architect or engineer.

TODAY'S TECHNOLOGY

Progress

Today's technology can best be described as a "forever changing state of the art." After each major earthquake, scientists and engineers seem to gain new insights as to how earthquake ground-shaking occurs and how man-made structures respond. The state of the art has advanced tremendously during the past 20 years as a result of the 1964 Alaskan Earthquake, the 1971 San Fernando Earthquake, other large but less notable earthquakes (e.g., Coalinga 1983), engineers' and scientists' success at obtaining instrumental recordings of earthquake motions and structural response, the "national" emphasis placed on understanding the earthquake phenomena to provide safe nuclear power plants, and the passage of the Earthquake Hazards Reduction Act of 1977.

The nuclear power industry can be contributed with being the catalyst that sparked a strong earthquake and earthquake engineering research program in the mid-1960s that may have peaked as we entered the 1980s.

Although a lot has been learned during the past 20 years, our current understanding of the earthquake phenomena and how man-made structures respond to such events still has many shortcomings.

Understanding the Problem

We now understand the general phenomena of what causes earthquakes based on the concept of plate tectonics. This concept applies very well on the West Coast of the United States. However, understanding the concept of earthquake occurrences at intra-plate locations like the midwestern and eastern parts of the United States is extremely lacking. The lack of understanding can be based on two primary reasons: infrequent earthquake occurrences and earthquake occurrences at depth with no surface faulting. We do know enough about intra-plate earthquakes to know that the same design and analysis principles that are used on the West Coast may not be directly applicable in the Midwest and East because of the infrequency of such events and the attenuation rates.

From a purely engineering point of view, a such high state of technology exists regarding our ability to analyze complex structures to great detail. The phenomenal growth of the computer industry has provided us with this capability. However, our understanding of material properties and our ability to construct structures to such precise detail is far behind. In fact, our ability to analyze and design structures to earthquake ground motions far exceeds our ability to understand what the motions might be.

PRACTICE KEEPING PACE WITH TECHNOLOGY

Lag Time

As engineers and scientists learn more about preparedness and mitigation of the earthquake hazard and our development of technology, they begin the process of adopting this new found knowledge to practice. Like any industry, when trying to put new technology into practice, there is a lag time. However, in the case of nuclear power plants where the Level I approach to preparedness and mitigation occurs, technology has been placed directly into practice with little or no lag time. The Level I approach to preparedness and mitigation has been the leader of the "earthquake industry." In the Level II approach, an assessment would be made of the new developments in the Level I approach and these developments would be either rejected or accepted as deemed appropriate and practical for the particular critical facility under consideration. For those developments deemed appropriate for a Level II application, the lag time was usually relatively short. Those developments not deemed appropriate for a Level II application have been put aside--it may take years before such developments become practice.

The lag time in getting new developments into practice at the Level III stage of application usually is several years unless the development results in the awareness of a serious deficiency in the Level III approach. Even then it would probably take one or two years to get the code bodies changed.

Dynamic Analysis--Practice

As an example of the difficulty of taking technological development and applying it to practice, let's consider the case of dynamic analysis. Dynamic analysis capability has been around for 30 years and engineers recognize that structures subjected to earthquake loads are more properly analyzed using some form of dynamic analysis. But in the UBC, which is an accepted nationwide Level III type application, there are no provisions for such analyses. This exists for several reasons including, for example, perceived added costs of doing such analyses which are more complex than a simple static analysis, an undergraduate engineering educational level that does not require a dynamic analysis background (reserving it for graduate students), perceived low earthquake hazards by engineers and the public, and the tendency to keep legislated codes as simple as possible in an attempt to insure more uniform application of such requirements.

Applied Technology Council

In an attempt to overcome the obstacles to placing current technology into the hands of practice in as practical a way as possible, the Applied Technology Council (1978) developed the Tentative Provisions for the Development of Seismic Regulations for Buildings. This effort began in the early 1970s and when the result was published in 1978, it represented a very good recommendation for earthquake technology transfer to

practice. Excellent work is still going on to substantiate and justify the cost benefits of this technology transfer. However, except for isolated cases on a voluntary basis, none of this technology transfer has actually occurred.

EXISTING CRITICAL FACILITIES

Although earthquake hazard preparedness and mitigation practices have been occurring for new critical facilities during recent years, very little has been done to retrofit existing critical facilities. Most owners are not willing to provide the funds to retrofit such facilities because of the high cost involved. The high costs occur when the retrofit requirements are based on bringing the existing facilities under total compliance of a Level I, II, or III approach.

To avoid the high costs of total retrofit, much can still be done in costing critical facilities to minimize the earthquake risks. For example, anchoring equipment and piping systems in existing facilities is an effective way to conduct earthquake hazard preparedness and mitigation procedure.

TECHNOLOGY TRANSFER COMMITMENTS

Several technology initiatives could be developed for the transfer of earthquake hazard preparedness and mitigation technology to practice. However, to be successful, several commitments must be made.

There must be a commitment by government, industry, and the public to appropriate the funds required for such initiatives. In addition, the public, industrial and government managers, and political representatives must have a reasonable understanding of what the earthquake hazards are in their area of concern. As stated earlier, the problem here is that other than in, say, California, the earthquake hazard is perceived by these groups to be no hazard. The professional groups--architects, engineers, and scientists--must do their utmost to understand the earthquake hazard and develop proper preparedness and mitigation procedures--technology transferred to practice. The political and industrial communities must be committed to support and promote the initiatives.

For critical industrial facilities, today's social and political environment in the United States is very conducive for obtaining the commitment of the public and the political community. To get the same level of commitment for many critical public facilities is, and will be, considerably more difficult and will not occur until the public has some understanding of the earthquake hazard. However, because critical facilities are "critical," there is an ever-increasing commitment by architects, engineers, builders, and owners to transfer today's earthquake technology to practice.

SUMMARY

Although scientists and engineers continue to strive for a better understanding of earthquake hazard preparedness and mitigation, the technological state of the art seems far ahead of that technology, except for highly visible and critical facilities, used in current practice.

An education program involving all phases of training is needed. However, public information and awareness programs should be placed at the top of the list. Until the public has a better understanding of what the earthquake hazards are, progress toward earthquake preparedness and mitigation will be slow unless regulation occurs--and regulators are the public.

REFERENCES

- Applied Technology Council. 1978. Tentative Provisions for the Development of Seismic Regulations for Buildings. Washington, D.C.: U.S. Government Printing Office.
- International Conference of Building Officials. 1982. Uniform Building Code. Whittier, California: ICBO.
- Manrod, W. E., W. J. Hall, and J. E. Beavers. 1981. "Seismic Evaluation Criteria for Existing Industrial Facilities." In Earthquakes and Earthquake Engineering: The Eastern United States, edited by J. E. Beavers. Ann Arbor, Michigan: Ann Arbor Science Publishers.
- Structural Engineers Association of California, Seismology Committee. 1975. Recommended Lateral Force Requirements and Commentary. Los Angeles, California: Structural Engineers Association of California.
- U. S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation. 1975. Standard Review Plan. Washington, D.C.: U.S. Nuclear Regulatory Commission.